Bluestone Lake Dam Stilling Basin Forces

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Abstract

As a result of the new Probable Maximum Flood (PMF) criteria developed by the National Weather Service, several Corps dams must be modified to pass a discharge higher than their original design discharges. There are several methods under investigation to accomplish this. Some Districts have studied, either individually or in combination, constructing emergency spillways, overtopping sections of the dam, and using parapet walls (increasing head). In an effort to meet the PMF criteria at the Bluestone Lake Dam (completed in 1949), a parapet wall was used to prevent overtopping of the dam, which produces a higher head and increases the spill discharge.

The US Army Corps of Engineer Research and Development Center (ERRD), Coastal and Hydraulics Laboratory (CHL) was tasked to prove that the installation of the parapet wall would provide PMF passage and determine the magnitude of the hydraulic forces acting on the stilling basin and its components. Installation of a parapet wall increased spill discharge by approximately 100% (450,000 cfs to 1,000,000 cfs). The increased spill capacity adequately met the PMF criteria.

This paper will focus on the modeling procedures used to measure the hydraulic forces in the stilling basin. The data that will be used in insuring the structural integrity of the unmodified Bluestone Lake dam stilling basin will also be presented.

Introduction

The Bluestone Lake dam was constructed as a multi-purpose concrete gravity dam and is located on the New River, near Hinton, WV. Completed in 1949, the structure consists of a 21 bay spillway, non-overflow and intake sections (Figure 1). The spillway is 790 feet long with a crest elevation of 1490[1] and contains 16 sluices to pass low pool flows. A stilling weir with crest elevation of 1391 is located just downstream of the spillway to maintain tailwater for energy dissipation. The intake section contains six penstocks for possible future hydropower generation. The top elevation of the dam is 1535.

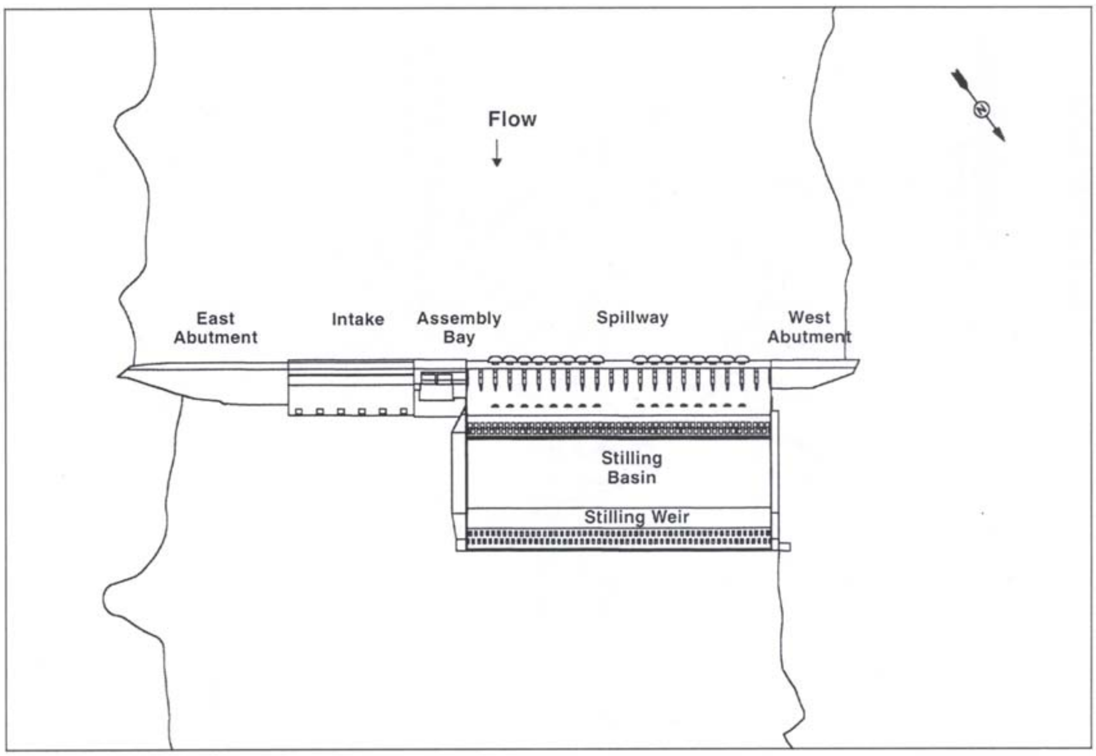

Figure 1. Bluestone Lake Dam plan view

As a result of the new Probable Maximum Flood (PMF) criteria developed by the National Weather Service, the dam must be modified to pass a discharge higher than the original design. In an effort to meet the PMF criteria, the top elevation of the dam will be raised, via a parapet wall, to allow a maximum pool elevation of 1542.2. The higher head on the dam, will increase spillway and sluice discharge to a level over their original design capacities. The higher head and emergency discharge through the penstocks will allow the dam to safely pass the PMF.

A previous model study was conducted to verify the discharge capacity of the Bluestone Lake dam after it is modified to provide flood control for the new PMF. In

[1] Unless stated otherwise, all elevations (el) cited herein are in feet as referred to in the National Geodetic Vertical Datum (NGVD) of 1929. To convert elevations to meters, multiply by 0.3048.

the course of this study, a concern arose as to the structural stability of the stilling basin and its components during high river discharges. To investigate these issues, a section model of the spillway and stilling basin was constructed. The 1:36-scale section model would be used for measuring the forces exerted on the baffle blocks and the end sill during flood events. Another study would be to measure the total hydraulic force acting on the stilling basin.

Our initial literature search produced to two pertinent reports, "Old River Low-Sill Control Structure: Dynamic Hydraulic Forces Acting On The Stilling Basin, Survey Boat Safety, And Debris Passage" (Fletcher, 1988) and "Baldhill Spillway Hydraulic Model Investigation" (Fletcher 1993). In these studies forces were measured in or near a stilling basin. In the first study, strain gages were used to measure vertical (uplift) and horizontal forces on a portion of the basin. In the second study, an array of pressure cells was used to measure uplift pressures on the apron just upstream of the baffles. Because the area of concern did not have vertical elements (baffle blocks or end-sill) no horizontal forces were measured.

Each approach (direct-measurement of force or distribution of pressure) has its advantages and disadvantages. The direct-measurement type of instrumentation gives the advantage of measuring forces in both directions simultaneously thus giving a time correlation. By having this time correlation, the resultant force does not necessarily use the maximum horizontal force at the same time it experiences the maximum vertical force. Peak horizontal and vertical forces do not always occur at the same time. If we assume that these peaks occur at the same time, the resultant force would be overly conservative and would likely yield a more robust (and more expensive) prototype fix. Another advantage of this approach is that the forces are measured directly. The gage output is the required force measurement and does not have to be distributed across a plan area of the basin to provide a force component (as with pressure measurements).

Disadvantages of this approach are that in order to make a force measurement the section of the basin to be measured must move slightly to load the gages. This movement has to be limited in magnitude to prevent the flow conditions around the structure from changing. The movement must also be limited in direction to insure the forces measured are the desired forces. The magnitude of movement is typically restricted by careful selection of gage ranges. The gages must be high ranging (able to measure large forces) to restrict movement, but be ranged low enough to allow force measurements in the model. These instruments are checked for low-load linearity.

The direction of movement is dealt with during model construction. When the instrumented section of the model is constructed, sleeves and bearing surfaces must be used to limit or restrict the direction of movement. Experience plays an important role in designing these components. However, in most cases or studies, the model will have enough subtle differences to require a somewhat unique instrument design.

The use of pressure cells also has its advantages and disadvantages. One of the advantages is that there are no moving parts of the basin. This reduces the possibility of having excess movement or incorrectly measuring a force component (one that is not purely vertical or horizontal). It also provides a better look at the load distribution across the basin, stream-wise and laterally, because you usually have a large number of instruments that give you an array of point pressures in the basin.

Testing

The first option was used for this study. If the area of interest had been clear such as on an apron approaching the basin, pressure cells would have been chosen. But because the pressure cells would have to be located near baffle blocks (in turbulent flow) it was determined that direct measurement of forces with load cells would provide a better answer.

The instrumentation device (Figures 2 and 3) was constructed to allow measurement in both directions simultaneously for time correlation of force components. The device has three plates that are used to isolate movement or force measurement in two directions. The bottom plate is fastened to a rigid frame. The middle plate can move horizontally and has two load cells that measure the horizontal force. The top plate moves vertically and the vertical force is measured with three load cells fastened between the top and middle plates.

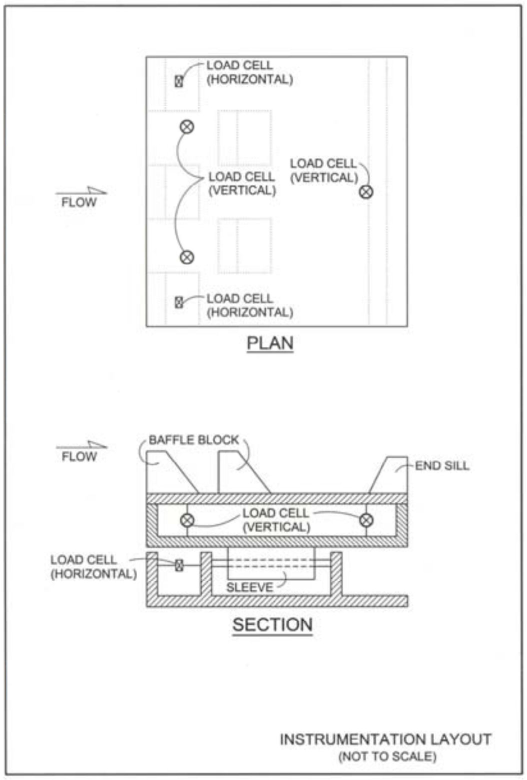

Figure 2. Instrumentation layout

Figure 3. Section of the stilling basin to be used for measuring forces

A machined sleeve with roller bearings is used to allow the upper two plates the freedom to move horizontally and produce a horizontal loading without vertical movement. The top plate is pre-loaded against stand-offs from the middle plate with the load cells. This pre-loading will be “zeroed” and relief from this loading will be recorded as uplift.

Again, with this set-up, both force components were measured simultaneously. The flow conditions used are show in the Table below. The study began with condition 1 and continued incrementally toward the PMF (flow 10).

Table 1
Investigated Flow Conditions

Condition Number	Discharge, kcfs	Pool Elevation, NGVD	Tailwater Elevation, NGVD
1	28.0	1415.0	1374.0
2	49.5	1455.0	1376.0
3	87.0	1480.0	1379.0
4	193.0	1505.0	1384.0
5	355.0	1515.0	1390.0
6	450.5	1520.0	1394.0
7	560.0	1525.0	1397.0
8	730.0	1530.0	1402.0
9	855.5	1539.0	1405.4
10	863.9	1542.2	1408.8
11	879.8	1546.8	1409.5

It became apparent rather quickly that the vertical gage output was not the true uplift forces. These gages were measuring extremely large forces. It was determined that the top plate was not moving only in the vertical direction. It had moved horizontally downstream and had started to pivot about the downstream edge of the endsill. With that, the horizontal loading (Fh in Figure 4), from the spill flow impacting the upstream face of the baffle blocks was creating, a moment about the endsill and putting a substantial uplift (Rv in Figure 4) on the upstream vertically oriented load cells.

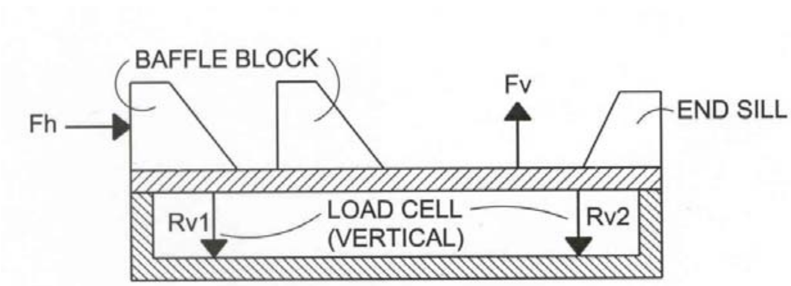

Figure 4. Vertical force schematic

To remedy this, the instrumentation layout had to be redesigned. We had to either better isolate the horizontal and vertical forces or provide a more robust means of limiting the upper plates movement in undesirable directions.

We had the option to isolate the forces by separating the baffles, endsill and basin floor (Figure 5) or go to the next best thing, use pressure cells in the basin floor. Due to the time constraints in getting design information to the Huntington District, we chose to use pressure cells.

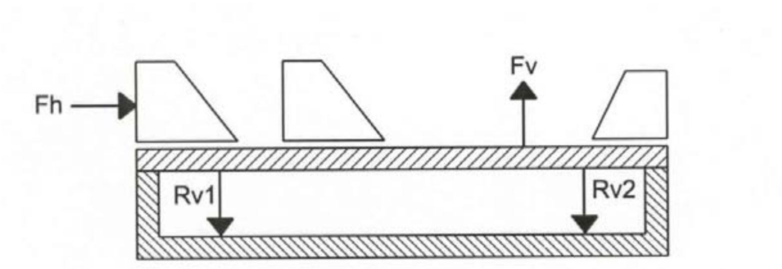

Figure 5. Schematic showing isolated baffles and endsill

Conclusion

The data from this study will be useful in determining necessary measures for insuring the integrity of the Bluestone Lake Dam stilling basin and its components during high flow events. By using horizontal force data (Figure 6) from the load cells and the pressure data, the resultant force and its location can be calculated.

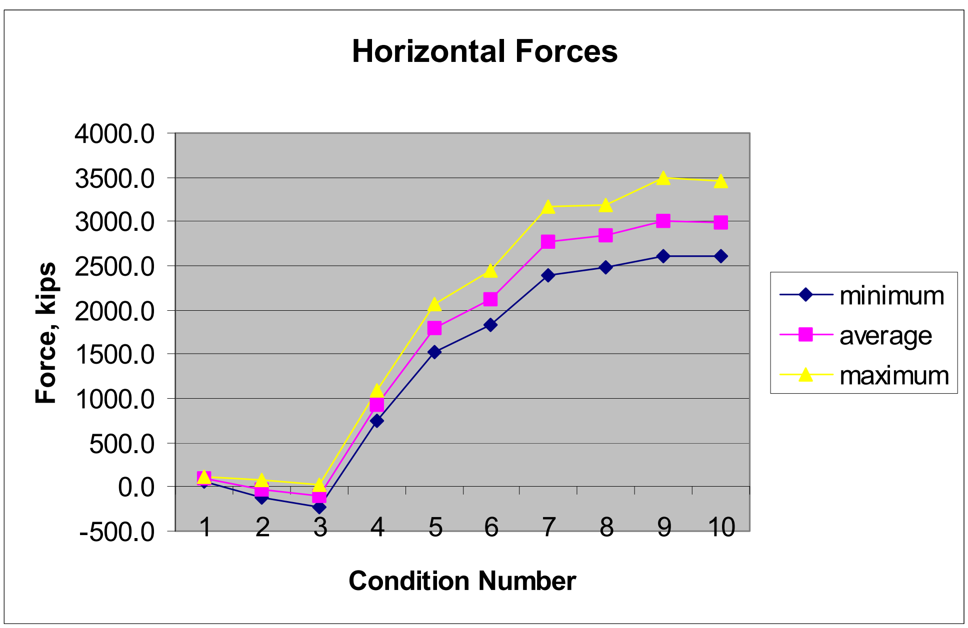

Figure 6. Horizontal force measurements

Lessons learned during this study will be valuable for the Engineer Research and Development Centers Coastal and Hydraulics Laboratory in future studies. The instrument layout used for future studies would be similar to that found in Figure 5 for stilling basins. If we were to look at forces on slabs that did not contain or were not as crowded with baffles, we would use a set-up that would simultaneously record load cells in the horizontal direction and pressure cells in the vertical direction.

References

Fletcher, Bobby P. (1988), "Dynamic Hydraulic Forces Acting On The Stilling Basin, Survey Boat Safety, And Debris Passage." U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report #HL-88-6, April 1988

Fletcher, Bobby p. (1993), "Baldhill Spillway Hydraulic Model Investigation." U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report #HL-936, July 1993